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Alternate #_____

SUBJECT

DESIGN & USE OF SOFIA BORESIGNT BOX FOR SCIENCE INSTRUMENT

ALIGNMENT

PROJECT SOFIA

DISTRIBUTION

$3X$

Design and Use of SOFIA Boresight Box for Science Instrument Alignment"
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DRAFT   9/10/90

Motivation -

   One of the design goals of SOFIA is that the telescope cavity be kept
sealed for long periods of time. Ideally, routine installation of science
instruments (SI), and pre-flight operational checks will be possible
without cavity intervention. Such a scheme is quite different from that on
the KAO, where SI alignment routinely involves cavity traffic for
installation of light sources, or long periods of time with the door fully
open in order to view external light sources. An alignment scheme that
presupposes a sealed cavity will serve three purposes:

- The cavity, and the optics contained within, will be kept clean. This is
  a matter of special concern at an urban airfield, where hydrocarbon
  pollution is a significant source of dirt. For background-limited work in
  the thermal IR, the low emissivity of a clean optical train is a
  requirement for optimal system performance. For work at visual
  wavelengths on (for example) planetary occultations and eclipses, a clean
  optical train will minimize scattered light that can interfere with
  observations. Without special measures to keep the optics clean, the
  system efficiency will suffer, either because of reduced detectivity, or
  because of extra down time that will have to be budgeted for mirror
  recoating/cleaning.

- The need for KAO-type line operations will be eliminated. SIs on the KAO
  that require line ops for boresighting are somewhat at the mercy of the
  local weather. It can be assumed that the manpower that gets invested
  in a KAO line op (that turns out to be clouded out) will be substantially
  exceeded on SOFIA if line operations are required.

- The amount of aircraft 'quality time' required by the SI team to do their
  alignment can be reduced. Alignment can proceed before the cavity
  finishes warming up from the previous flight, and can proceed well into
  the precool period for the first SI flight. Alignment checks can be done
  between flights without warming the cavity up at all. The turn-around
  time between SI teams will thus be reduced.

   The boresight box (BB) attachment to the SI answers to this goal of a zero
traffic cavity for routine alignment operations. The role of this unit in
the complete alignment procedure is outlined in the document "Alignment
Procedures for the SOFIA Telescope and Science Instruments". Functionally,
the BB must

- allow the SI team to define a FPI/SI boresight for their instrument
  (eliminating the need for mounting the PCLS on the telescope, as well as
  KAO-type line operations.)

- allow the SI team to determine, or at least check that the SI beam is
  optimally pointed at the secondary and tertiary mirrors (eliminating

the need for a chopped hot plate (CHP) to be mounted inside the cavity
as it is for the KAO).

- have minimal complexity to encourage its use, to increase the confidence
  with which it is used, and to allow several to be available at any one
  time for instruments that are in different stages of flight preparation.

- not seriously impact the flexibility with which SIs can be mounted on the
  SOFIA Nasmyth mounting plate.

- be rugged enough to travel (with the SI) from the simulator in the lab
  to the telescope without compromising the alignment, and may be required
  to support a large fraction of the weight of the SI for certain light
  instruments.

- have a FOV that includes the optical axis of the telescope, but need not
  cover the entire 8' FOV of the telescope without vignetting. This
  simplification is based on the presumption that every SI will have at
  least one detector that is close to the telescope optical axis, and that
  boresighting this detector will allow indirect boresighting of the others.

Design Considerations for BB -

  The function of the BB is to allow most aspects of the SI alignment to be
carried out on the SOFIA simulator, and then transferred over to the
telescope after installation. Three facets of this alignment are made
possible - optimal SI beam-line alignment with secondary, FPI/SI boresight,
parfocalization of FPI with SI.

  The BB has one moving part - an insertable mirror for standing in at the SI
focal plane, and two imagers. The BB mirror must intercept at the entire
telescope beam at least when the beam coincides with the boresight SI. The
mirror must retract out of the beam entirely for any position in the FOV of
the telescope. When inserted, this mirror must position itself reproducibly
to within ~1 arcminute. This is required for BBFI/SI boresight stability
at the 0.3 arcsecond level for all focus positions. Ideally, this
insertion/retraction will be able to be done remotely. This feature would
allow frequent checks of the boresight stability without leaving the
console area.

  The BB pupil plane imager (BBPI) is set up with a fixed position, and focus.
This focus is in the far field, and is intended to allow the BBPI to image
the secondary mirror. The BB focal plane imager (BBFI) must be configurable
so that it can be parfocal with any SI, and thus must reach the specified
focus range of the telescope. It is not necessary that the BBFI focus over
this entire range for each SI, and alternate BBFI locations will allow the
BBFI to par-focalize with different instruments. In the case of both
imagers, it is not necessary to specify high sensitivity. For the BBPI, it
need only be necessary to see the chopped hot plate (CHP), and the
telescope secondary when they are illuminated by room, or cavity lights.
The BBFI need only be sensitive enough to see the image from a laboratory
light source, and fro mreasonably bright stars. Many kinds of inexpensive,
off-the-shelf commercial imagers will serve these purposes, and can reach

the required focus range with standard commercial photography lenses. Both imagers should have a pixel format that is stable with respect to operating voltage level and large changes in ambient magnetic fields. It is noteworthy that small, lightweight, inexpensive, gated MCP CCD imagers are commercially available that satisfy all of these criteria. These imagers will be capable of seeing V<10 stars at video rate through the SOFIA (even with the ~1 magnitude handicap of fixed beamsplitters -see below).

The alignment of the SI beam to point to the secondary can be carried out with the BB in a manner that is analogous to boresight determination. When the SI is on the simulator, it is tipped to peak up signal on the chopped hot plate (CHP). The position of the chopped hot plate is recorded in the BBPI. When the the SI is mounted on the telescope, it is tipped so that the secondary mirror falls in exactly this position. If the simulator is aligned in such a way that it looks, to the SI, like the telescope, then the optimal SI tilt will be transferred to the telescope by the SI mount, and the BBPI is available as a check.

The boresighting of the SI is done on the simulator using the portable chopped light source (PCLS). The PCLS produces a focussed image of a source that is visible both optically and by the SI in the SI focal plane. The PCLS is adjusted until the image of this source is centered on the SI aperture, and is correctly focussed for the SI. The position of this image in the BBFI is then established. This defines the BBFI/SI boresight. Once in flight, just before the first object, a 'transfer' star is acquired on the BBFI/SI boresight. The telescope secondary is moved to focus this image on the BBFI. This star is to be used simply as a fiducial, and need not be visible to the SI. When acquired, the position of the star in the FPI is noted. This is the FPI/SI boresight, and can be checked anytime during flight.

Figure 1 is a schematic for a BB concept. The aft end of the BB provides the same mounting hole pattern as the BB takes up on the Nasmyth mounting plate. The retractable mirror is shown as (A). The light path is folded using fixed beamsplitter mirrors (B) and (E), and first surface mirrors (C) and (D). The advantage of fixed beamsplitter versus flip-mirrors is that, aside from the movable mirror (A), the entire light path is fixed. The only disadvantage of beamsplitters is that, for ~50% reflection and transmission, the BBPI will only see half of the light from the illuminated secondary, and the BBFI will either see about half or one-quarter of the light from the transfer star. Since neither alignment imager will be photon starved, this is not considered to be a problem. The BBPI is fixed in position and focus at (F), and the BBFI is either at position (G) or (H) depending on whether the telescope focus is parfocalized on the SI inside or outside the nominal telescope focus. With two possible positions for the BBFI, the plate scale (in arcsec/pixel) will be a function of the focus position. As long as the BBFI focus is not changed after the simulator is used, however, and as long as the magnification is such that the image is always spatially oversampled, this variable magnification will not hinder the boresighting operation.

Step-by-Step Use of BB -

The alignment procedure may be broken down in to discrete steps. These steps are a subset of the general installation procedure that is outlined in "Alignment Procedures for the SOFIA Telescope and Science Instruments".

The alignment of the simulator (0.n) need not be done frequently. Alignment of the SI with the simulator (1.n) and (2.n) will be done once for each installation. Boresight transfer (3.n) will be done at least once per flight.

Alignment of simulator:

(0.1) An alignment telescope is mounted on the BB. The combination is mounted on the main telescope. The alignment telescope is aimed at the center of the secondary, and fixed at that angle.

(0.2) Alignment telescope/BB combination is carried over to the simulator. The mounting bracket for the PCLS and CHP is adjusted so that, with respect to the mounting flange, the simulator is identical to the main telescope. Both the PCLS and CHP, when mounted, will locate themselves in a position relative to the simulator mounting plate that is identical to that of the telescope secondary relative to the Nasmyth mounting plate on the telescope.

Alignment of SI with simulator:

(1.1) Mount BB on SI. Combination is mounted on simulator. SI beam is adjusted to peak the signal on the CHP. BBPI is used to record the location of the CHP in screen coordinates on the image from this camera.

(1.2) PCLS replaces CHP on the simulator. Flux focus and orientation are adjusted to give peak signal on the SI. The BBPI is focused on this peaked PCLS image. If the BBPI cannot be particularized in one BBFI mounting position, then it is moved to the alternate mounting position. The screen coordinates of the PCLS image from this camera is recorded. This is the BBFI/SI boresight position.

Pre-flight alignment check:

(2.1) SI (with BB) is mounted on the telescope. With the cavity lights on, verify with the BBPI that the beam tilt of the SI/BB is correct. If it is, the image of the secondary will coincide with the image of the CHP in this camera. Can check this for different telescope elevations.

In-flight determination of FPI/SI boresight using transfer star:

(3.1) Acquire *any* reference star in the BBFI. Move the telescope to put this star on the BBFI/SI boresight. Note that this star need not (and generally will not) be visible with the SI.

(3.2) With the transfer star centered on the BBFI/SI boresight, identify the same star in the FPI. Record the FPI position. This is the FPI/SI boresight. Extract the movable BB mirror from the beam, and observe. Note that, given a stable SI, and a sturdily built BB, this BBFI/SI

boresight can be checked at any time in the flight.

Boresighter Box Alignment

Boresighter box alignment concept addresses the problem of aligning a SI on SOFIA with a zero traffic cavity that can be kept sealed.

This serves three purposes:

(1) Keep cavity (and optics) clean, and perhaps even cold.

(2) Reduce the amount of a/c time that is required to install a new SI on the telescope.

(3) Eliminate the need for line operations (requiring favorable weather) for near-IR boresight determination.

Boresighter box must:

(1) allow SI team to define a boresight on their instrument (replacing PCLS on telescope as for KAO)

(2) allow SI team to determine, or at least check on optimal SI beam tilt (replacing CHP on telescope as for KAO)

(3) have minimal complexity to encourage its use, and to allow for several to be available

(4) not seriously compromise the flexibility of SI mounting on SOFIA

(5) be rugged enough to travel with the SI from lab to telescope without compromising the alignment, and may be required to support a large fraction of the weight of a SI

(6) have a FOV that includes the optical axis of the telescope, but need not cover the entire FOV of the telescope (8'). Assumes that SI has some detector close to the telescope optical axis.

While a separate box could be provided by the facility to attached to each SI, it could be simply required that the wherewithal to do this kind of alignment be built into each SI (ie telescope mounted PCLS and CHP not be routinely supported).

Boresighter Box Options

1) view unfocussed image of PCLS and ref star on the back of a flip screen

    advantages: - simple, compact package

    disadvantages:
- requires bright star for boresight transfer
- boresight is based on centroid of a defocussed
  star image (<20 arcseconds in size)
- cannot image pupil to check beam tilt

2) view focussed image of PCLS and ref star star off of flip mirror directly

    advantages:
- compact package
- view focussed image, see faint ref stars

    disadvantages:
- cannot use commercial optics entirely
- optical arrangement will depend on focus
  position (move lenses around, etc.)
- can image pupil to check beam tilt only by
  moving optical components

3) view focussed image of PCLS and ref star off flip mirror with folded beam

    advantages:
- view focussed image
- commercial optics
- optical arrangement independent of focus location
- using beamsplitter, can image pupil to check beam
  tilt simultaneously with boresight determination

    disadvantages:
- somewhat less compact package

One disadvantage for each of these concepts is that the box cannot
be used in the foreward mounting location.

Use of Boresighter Box

Alignment of simulator

(0.1) Alignment telescope is mounted on boresight box (BB); combination is mounted on telescope, and the alignment telescope is aimed at the center of the secondary. (Alignment telescope need not be exactly on the optical axis of the main telescope.)

(0.2) Alignment telescope/BB is mounted on simulator. Simulator PCLS/CHP mounts (fiducial secondary mirror position) are adjusted so that, with respect to the mounting flange, the simulator is identical to the telescope.
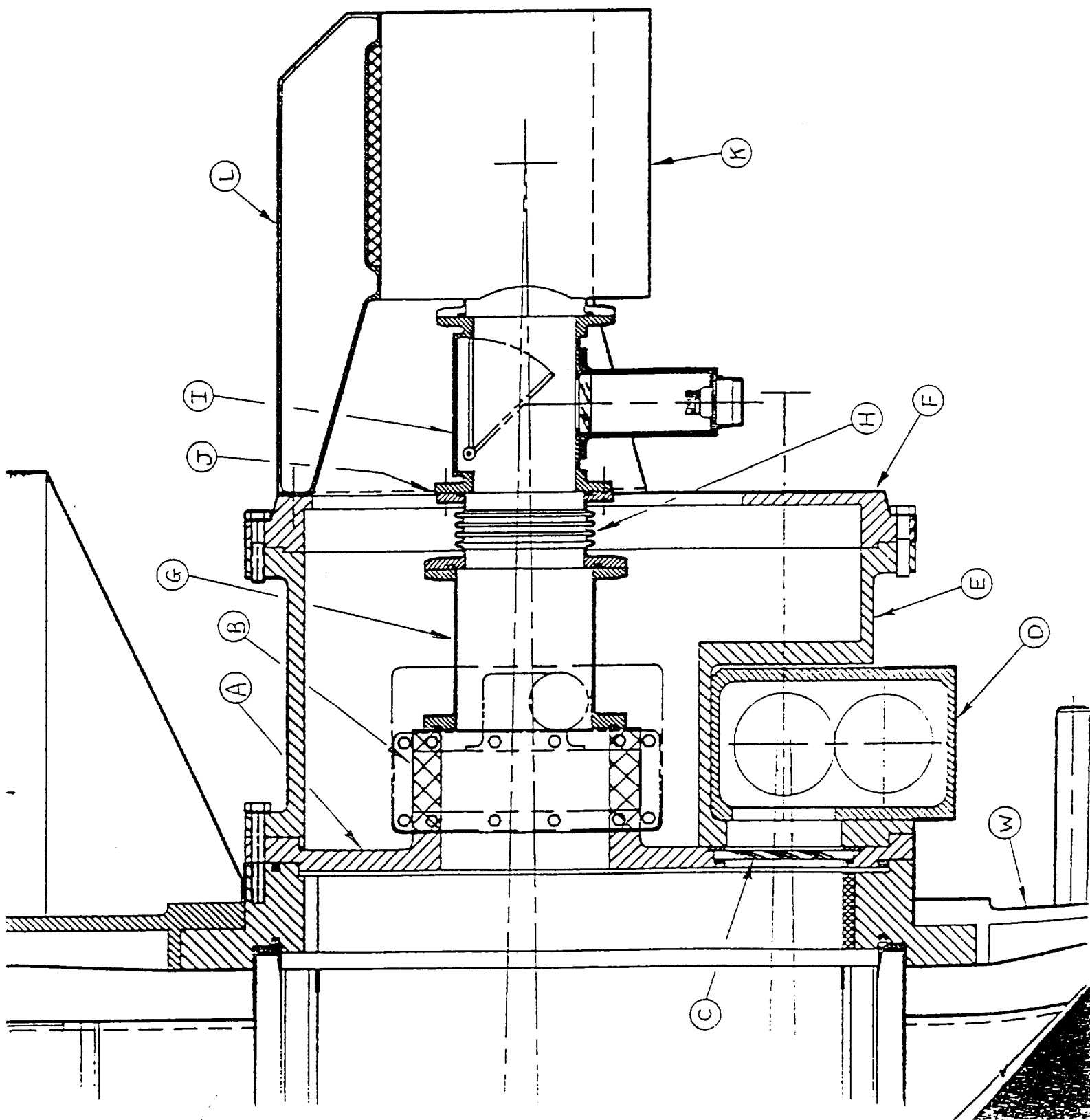
Alignment of SI with simulator

(1.1) SI is mounted on boresight box. Combination is mounted on simulator. SI beam is adjusted to peak signal with CHP. Pupil camera on BB is used to record the position of CHP in screen coordinates on the imager.

(1.2) PCLS replaces CHP on simulator. PCLS focus and angle are adjusted to give peak signal on SI. Boresight camera on BB is used to focus on, and record position of PCLS image in screen coordinates on the imager.
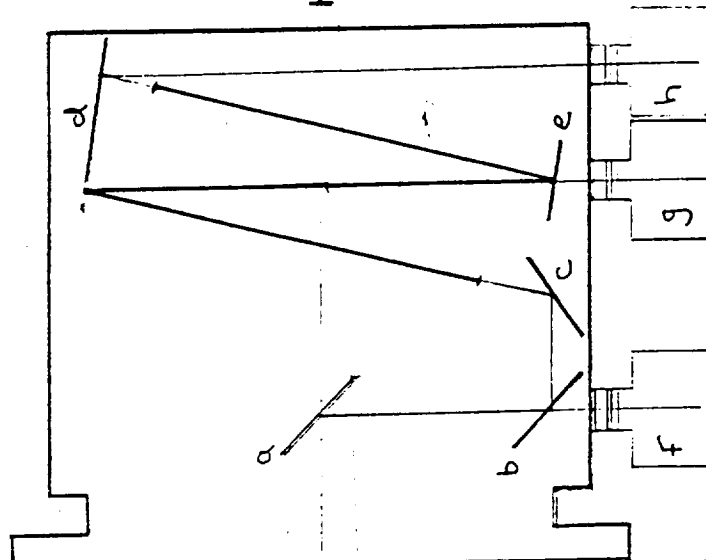
Pre-flight alignment check

(2.1) SI/BB is mounted on telescope. With cavity lights on, verify with pupil imager that beam tilt of the SI/BB is correct by comparing the position of the secondary to that recorded in (1.0). This check can be done anytime. This check could also serve to verify that the lateral flexure compensation on the secondary is working properly, and that the beam tilt is optimal for all telescope elevations.

In-flight boresight transfer using reference star

(3.1) Acquire *any* optically bright reference star in the boresight camera. Center the star on the boresight position recorded in (1.1). Note that this star need not (and generally will not) be visible with the SI.

(3.2) With the star centered on the boresight camera, acquire the same star in the FPI. Record position on the FPI. That's the FPI/SI boresight. Retract flip mirror, and observe.

Fig.

Boresight Box
1/4 scale

Normal viewing point

Focus range ±35cm

nominal focus 65cm → mounting plate

8' FOV

a

b

c

d

e

f

g

h

a: retractable mirror

b, e: fixed beamsplitter

c, d: fixed mirror

f: pupil imaging camera; focus fixed at ∞

g, h: alternate mounting positions for boresight imaging camera

focus range 28cm ↔ 62cm